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TECHNICAL REPORT

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AN AERIAL SURVEY OF WATER TURBIDITY AND LASER DEPTH SOUNDING PERFORMANCE ALONG THE QUEENSLAND COAST

D.M. PHILLIPS and R.H. ABBOT

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SUMMARY

The performance of the WRELADS laser airborne depth sounder has been assessed in North Queensland coastal waters from Townsville to Torres Strait. This was achieved by recording water turbidity and maximum sounding depth in the aircraft along the flight path. The parameter used in the aerial survey as a measure of water turbidity was related to beam attenuation coefficient measured from a boat in a joint aircraft and boat trial. Data relating the statistical distribution of turbidity to water depth were obtained and compared with the observed performance characteristic in order to indicate the proportion of Queensland coastal waters suitable for sounding with an airborne laser sounder.

POSTAL ADDRESS: Chief Superintendent, Electronics Research Laboratory, Box 2151, GPO, Adelaide, South Australia, 5001.

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1. INTRODUCTION

The laser airborne depth sounder (WRELADS) being developed at the Defence Research Centre Salisbury to assist the Royal Australian Navy in its task of charting Australian coastal waters, is described by Clegg and Penny(ref.1). The results of trials in the development program have been reported by Abbot et al(refs.2,3).

The performance of the depth sounder is limited by the turbidity of the water beneath the aircraft through which the laser pulse must travel. The influence of water turbidity on the maximum depth that can be measured by the system has been studied experimentally by Phillips(ref.4) during a joint aircraft and boat trial. The water turbidity was characterised by the beam attenuation coefficient, which was derived from measurements made with a transmissometer lowered into the water from a boat. The maximum measurable depth in a given type of water, called the extinction depth, was estimated from return signals recorded by the WRELADS system in the aircraft.

The need for a boat to work in conjunction with the aircraft imposed a severe limitation on the amount of data that could be collected and hence the reliability of the performance characteristic derived from the experiments. In an effort to overcome the limitations imposed by the need for a boat, an attempt was made to determine water turbidity from the aircraft during a trial in June 1980. This joint aircraft and boat trial, carried out in St Vincent Gulf in South Australia, shows that water turbidity can be related to the shape of the backscatter signal under certain circumstances. The results of this trial are described by Phillips et al(ref.5).

In this report, techniques for measuring water turbidity from an aircraft are studied more carefully and used in an aerial survey of Queensland coastal waters from Townsville to Torres Strait. The results of this extensive survey allow the depth sounding performance of the WRELADS system to be specified over a wide range of water turbidity.

2. MEASUREMENT OF WATER TURBIDITY IN SITU

Water turbidity is due to the two primary processes of absorption and scattering. The beam attenuation coefficient, which is the sum of the attenuation and scattering coefficients, can be derived from measurements made with a water transmissometer. Such measurements have formed the basis of previous studies of water turbidity(refs.4,5). However, there is good reason to believe that the performance of the laser depth sounding system is more closely related to the diffuse attenuation coefficient K. For this reason the relationship between the diffuse and beam attenuation coefficients were investigated experimentally.

2.1 Beam attenuation coefficient

The beam attenuation coefficient is an intrinsic parameter of the water, that is, it depends on neither the ambient lighting conditions nor on the design of the instrument used to measure it. As a parameter used to describe water turbidity it has several advantages. Firstly, measurements performed by different people at different places and times can be directly compared. Secondly, measurements can be made both at night and during the day. Thirdly, it has a precise definition and can be used in theoretical modelling. Fourthly, it can be derived from a single measurement with a suitable instrument.

The beam attenuation coefficient is an exclusive measure of turbidity in the sense that it excludes from consideration all absorbed and scattered

light. It therefore provides a measure of the amount of direct light passing through a section of water. However, the laser depth sounder makes use of all the light transmitted to the sea bed and back to the surface, whether it is scattered or not. Consequently, the beam attenuation coefficient is not the most appropriate measure of turbidity for describing the performance of the depth sounding system.

The measurements of beam attenuation coefficient given in this report were derived from measurements of water transmittance made with the transmissometer described by Woodcock(ref.6). The instrument maintains a constant lamp brightness so that the water transmittance can be determined from a single reading.

2.2 Diffuse attenuation coefficient

The diffuse attenuation coefficient is not strictly an intrinsic property of the water. It describes the attenuation with depth of the downward irradiance within the water, which depends on the angular distribution of the downwelling light. Different values of the diffuse attenuation coefficient can occur in the same water, depending on whether the ambient light is dominated by directional sunlight or by diffuse skylight.

The values of diffuse attenuation coefficient given in this report were derived from measurements of the downward illuminance in the water as a function of depth. The measurements were made with a Lambda Licor sensor kindly made available by the School of Biological Sciences in James Cook University.

These measurements suffered from three problems. Firstly, the meter measured illuminance, not spectral radiance. Therefore, although it was most sensitive in the green region of the spectrum it was nevertheless not confined to the laser wavelength of 532 nm. Secondly, on the day of the trial the sky was partly covered with cloud and the ambient light varied from direct sunlight to overcast conditions. This resulted in variations in the measured illuminance and hence uncertainty in the derived values of K. Thirdly, the instrument was lowered over the side of the RAAF search and rescue boat and the readings could at times have been influenced by the boat's shadow.

The results of the simultaneous measurements of the diffuse and beam attenuation coefficients are presented in figure 1. The open circles represent the actual measurements and the line is a regression line through those points. It can be seen that a linear relationship between the two variables provides a good fit to the data. However, the regression coefficients differ from those given in an NADC publication(ref.7). Nevertheless, the differences between the two sets of data are within the errors associated with the two instruments.

Since both attenuation coefficients are affected by two independent processes, namely absorption and scattering, the difference between US and Australian data could be due to different water types, although the available data are too limited to confirm that.

3. MEASUREMENT OF WATER TURBIDITY FROM AN AIRCRAFT

The attempt to measure water turbidity from an aircraft by measuring the amplitude and attenuation of the backscatter signal from a pulsed laser reported by Phillips et al(ref.5) was hindered by a number of errors. The main errors resulted from inadequacies in the theoretical model used to analyse the data when the water was either horizontally stratified or

relatively shallow.

The data obtained during the North Queensland trials in August 1980 should be more accurate for the following reasons. Firstly, the aircraft and boat measurements were again made within a few minutes and within one hundred metres of each other, thereby minimizing errors due to horizontal variation in turbidity. Secondly, the water turbidity was observed to be vertically layered and variations in the beam attenuation coefficient were only a few percent over the full range of water depth. Thi y, the water was in general deeper than that in South Australia and longer backscatter curves were recorded.

3.1 Backscatter amplitude

The amplitude of the backscatter signal depends on the operating conditions of the green receiving system. The conditions applicable to the results presented in this report are as follows:

Filter Band Width	0.2 nm
Filter emperature	24°C
Polarizer Orientation	Crossed
Photomultiplier Tube	EMI 9813 KB, Ser.No. 12437
Photomultiplier Voltage	2100V
Photomultiplier Dynode Conditions	constant gain

The backscatter signals were recorded by photographing several traces on an oscilloscope using polaroid film. Points were subsequently read from the photographs and subjected to the regression analysis described in reference 5. Once the regression coefficients were calculated the amplitudes of the backscatter signal at the depths 1, 2 and 5.6 m were calculated. In all cases the amplitude of the backscatter signal is given as the voltage at the input to the Biomation Waveform Recorder.

The results of the analysis are presented in figure 2. It can be seen that values of the beam attenuation coefficient range from about 0.5 to 6 m^{-1}. The absence of data for relatively clear water was due to the strong winds and rough seas experienced throughout the trial. The scatter of the data is greatest at all depths when the turbidity exceeds 5 m^{-1}.

The closest approximation to a linear relationship between backscatter amplitude and beam attenuation coefficient occurs at a depth of 1 m. At 2 m depth the relationship appears to be linear until a beam attenuation coefficient of 5 m^{-1} is is reached. However, at a depth of 5.6 m the aplitude reaches a peak at about 3 m^{-1} and then falls again. The reason is that the most turbid water attenuates the beam so rapidly that its amplitude at 5.6 m depth is greatly reduced.

The line labelled "assu d calibration" was used to produce the data reported in Section 3 . The depth of 5.6 m was chosen because it corresponds to the f rst vertical division of the oscilloscope and facilitates real time measurements in the aircraft when regression analysis is not possible.

3.2 Backscatter attenuation coefficient

The attenuation coefficient of the backscatter envelope was derived from the same regression analysis used to determine the backscatter amplitude. The results are presented in figure 3. Substantial scatter is evident for the data in the turbid water. The regression line shown in the figure indicates that a linear relationship is again a good fit to the data.

It is noteworthy that the gradient of the backscatter attenuation regression line is only one third of the gradient of the diffuse attenuation coefficient line. In other words the backscatter envelope decreases more slowly than would be expected from diffuse attenuation. Possibly, as the laser beam penetrates the water, it becomes more diffuse and scatters a greater proportion of its light upwards to be recorded as backscatter.

3.3 Relationship between backscatter amplitude and attenuation coefficient

Since both the backscatter amplitude and the backscatter attenuation coefficient exhibit a linear dependence on the beam attenuation coefficient they are expected to be linearly related to each other. Figure 4 shows that the two backscatter parameters do indeed exhibit a linear relationship within the experimental error.

This is a significant result because the two parameters are in principle independent since they depend in different ways on the two independent processes of absorption and scattering. The backscatter amplitude is dependent only on scattering whereas the backscatter attenuation coefficient is probably influenced more strongly by absorption than by scattering. The linear relationship suggests that absorption and scattering are related in practice for the water types studied during these experiments. It is still possible, however, that the relationship could be different for other water types.

3.4 A survey of Queensland coastal waters

On 9 and 10 August 1980, the aircraft flew a long trial around Cape York Peninsula following the route shown in figure 5. Along the eastern coast the aircraft passed over many reefs, zigzagging from close to the shore to the outer parts of the reef.

Throughout the flight the amplitude of the backscatter signal at 5.6 m depth was recorded periodically by hand from the oscilloscope trace as mentioned in Section 3.1. This made it possible to attempt for the first time a large scale survey of turbidity in North Queensland coastal waters. In the most turbid water, where the beam attenuation coefficient exceeded about 3 m^{-1} the backscatter signal continued to grow in amplitude but the decayed time was so short that the amplitude at 5.6 m began to fall. In this region a subjective estimate of the turbidity was made.

The need for a subjective estimate arose because water with such a high turbidity had not been anticipated and because the calibration experiment that yielded data for figure 2 was performed only after the trial.

The most important result to emerge from this survey of turbidity is that the values ranged over two orders of magnitude, from 0.05 to 5.0 m^{-1}. The clearest water was encountered on the outer part of the reef where the water originated from the Pacific Ocean. The most turbid water was observed in Torres Strait where the relatively shallow water was being agitated strongly by a steady 35 kn wind that had blown for several days.

The importance of developing techniques for measuring water turbidity from an aircraft can be seen from the vast area of water surveyed in a relatively short time.

4. EFFECT OF WATER TURBIDITY ON LASER DEPTH SOUNDING PERFORMANCE

The performance of the WRELADS system may be specified in terms of the extinction depth: the maximum depth that can be measured in water of a given turbidity. A knowledge of the dependence of the extinction depth on the beam attenuation coefficient allows two important predictions to be made. First, if the water turbidity and approximate depth in a given region are known, then it is possible to predict whether the WRELADS system can sound the depths reliably. Second, if the return signal does not exhibit a bottom pulse then the minimum possible depth of the water at that point can be predicted.

4.1 Measurement of depth sounding performance characteristic

On the flight around Cape York Peninsula on 9 and 10 August 1980 estimates of the extinction depth were made at every opportunity and the results are presented in figure 6. It can be seen that extinction depths ranged from 50 m in clear ocean water (eg in the vicinity of Ribbon Reef) to as little as 3 m in the turbid waters of the Gulf of Carpentaria north of Weipa. Along the return track south of Weipa no bottom reflections were detected because the water was too turbid.

If the extinction depth is inversely proportional to some effective attenuation coefficient then a plot of the reciprocal of extinction depth against beam attenuation coefficient should produce a linear trend. Such a plot is shown in figure 7, together with the regression line through the points. A considerable amount of scatter is evident for the more turbid water, probably due to the difficulty in estimating from the aircraft both the extinction depth and the beam attenuation coefficient. In the clearer water, however, the points are grouped more closely and do indicate a linear trend.

The same results are plotted again in figure 8 in a different way - extinction depth is plotted against beam attenuation coefficient on a logarithmic scale. The linear regression line from figure 7 is shown as a curved performance characteristic. It can be seen that the system can sound to a depth of about 50 m in the clearest ocean water, to about 30 m in coastal water, and only about 4 m in the most turbid water encountered.

4.2 Statistical distribution of turbidity with depth

An important question that needs to be answered is what percentage of coast can be sounded by the WRELADS system. In other words, for water of a given depth what percentage has a turbidity below that given by the WRELADS performance characteristic.

One set of results obtained during a boat trial on 18 and 19 August 1980 is shown in figure 9. The beam attenuation coefficients plotted were derived from transmittance measurements at a depth of 2 m. Ideally the data should have been obtained at a uniform horizontal density throughout a defined region. However, that was not possible and the data were recorded at regular intervals along the boat track which zigzagged from shallow to deep water in order to cover a reasonable range of different water types. It can be seen that the results fell into two groups. The water near the coast was very turbid to a depth of about 15 m where it suddenly became much clearer. From the boat this was seen as a distinct change in water appearance. The second type of water was associated with the off-

shore Palm Isles where the water was much clearer. The high turbidity of the coastal waters resulted from the strong winds and rough seas which stirred up mud from the bottom. According to a post-graduate student at the James Cook University, Mr Terry Walker the coastal water becomes much clearer in calm conditions. It is therefore probable, although not established by the present results, that the coastal waters will be able to be sounded with the WRELADS system in more favourable circumstances.

For comparison, the statistical distribution of turbidity with water depth measured in South Australian waters is reproduced in figure 10, together with the performance characteristic shown in figure 9. It is evident that most of the South Australian waters sampled could be sounded with the WRELADS system.

5. DISCUSSION

5.1 The Performance characteristic

The performance characteristic in figure 8 is the first one to be obtained for the WRELADS II system. It indicates a better performance than that determined for the WRELADS I system in 1977 (see figure 11).

The scatter of the data in figure 8 is no doubt due to the limitations of the experimental technique. The estimation of extinction depth and the beam attenuation coefficient from a rapidly changing wave form in real time must be somewhat subjective. Furthermore, the depth of 5.6 m chosen for the estimation of turbidity was subsequently shown to be unsuitable and the data are rather sparse in shallow turbid water.

Now that the technique has been proved useful, a more accurate performance characteristic should be obtainable by maintaining stricter control over the experimental determination of the two parameters.

Should it be necessary to change the photomultiplier the absolute calibration of the backscatter amplitude would be lost. It would therefore be desirable to supply a small light pulse of constant amplitude to the photocathode of the photomultiplier in order to calibrate the gain of the system.

5.2 Distinguishing different types of turbidity

The linear relationship shown in figure 4 between the backscatter attenuation coefficient and the amplitude of the backscatter envelope is a significant result. Since the backscatter attenuation coefficient should be strongly influenced by absorption in the water, whereas the backscatter amplitude at the surface should be independent of absorption, the two parameters are principle independent. The linear relationship observed could be characteristic of the kind of matter contributing to the water turbidity. During these trials the main contributor to the water turbidity was the sediment agitated into suspension by wave action. At the location of these measurements, the sediment is primarily clay and silt from the Burdekin River carried northward along the coast according to Belperio (ref.8). Future experiments in waters where other factors are the main causes of turbidity could well reveal different relationships between these two parameters.

5.3 Performance characteristic at night

One night trial was flown in order to determine whether the performance characteristic at night was different from that shown in figure 8 for daytime operation. In clear water, where the performance is limited by noise from background sunlight, it is expected that greater extinction depths could be achieved at night. The few data points obtained during the night trial were close to the daytime performance characteristic in the region of beam attenuation coefficient between 0.05 and 0.2. The failure to achieve greater depth penetration is attributed to system noise.

5.4 Influence of meteorological conditions

Since the statistical distribution of turbidity with water depth (figure 9) indicates that the majority of water sampled could not be sounded using the WRELADS system, the influence of meteorological conditions on water turbidity needs further study. Favourable environmental conditions will probably be needed for the WRELADS system to sound the most turbid coastal regions.

6. CONCLUSION

It has been shown that useful measurements of water turbidity can be made from an aircraft. This provides a powerful technique for carrying out large scale rapid surveys of water turbidity. It should now be possible to study the influence of meteorological conditions on water turbidity so that the latter can be predicted.

The results have yielded the first performance characteristic of the WRELADS II system based on a large amount of data.

7. ACKNOWLEDGEMENTS

We are indebted to the pilots of the RAAF Dakota, FLTLT R. Boryscewicz, FLTLT M. Phillips, FLTOFF D. Jansen, and to the skipper WARR H. Webster and crew of the RAAF SAR boat for cooperating so well during the trials. We also wish to thank all those who have contributed to the WRELADS project and especially LEUT M. Gale, Messrs G. Watts, D. Faulkner, A. Thompson, W. Henschke and R. Hussey for assistance in preparing for the trials, obtaining measurements, and analysing the data.

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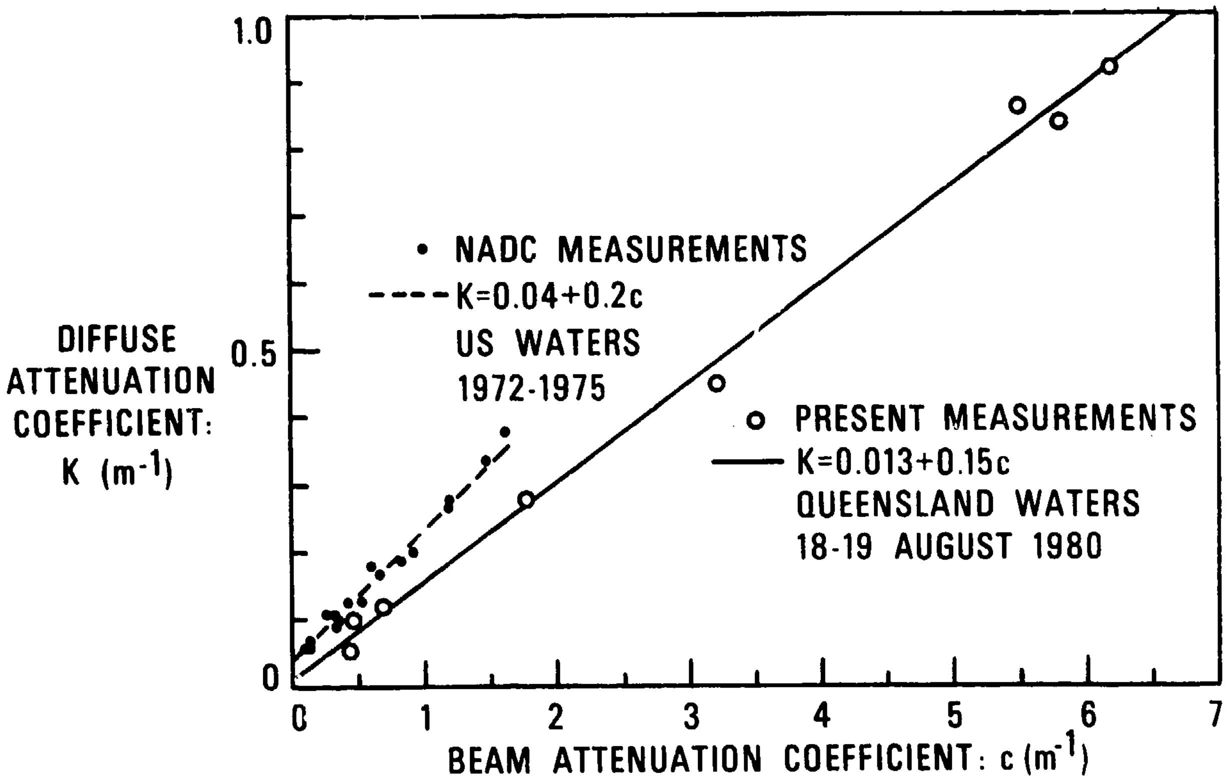

Figure 1. Measured relationship between diffuse and beam attenuation coefficients of sea water

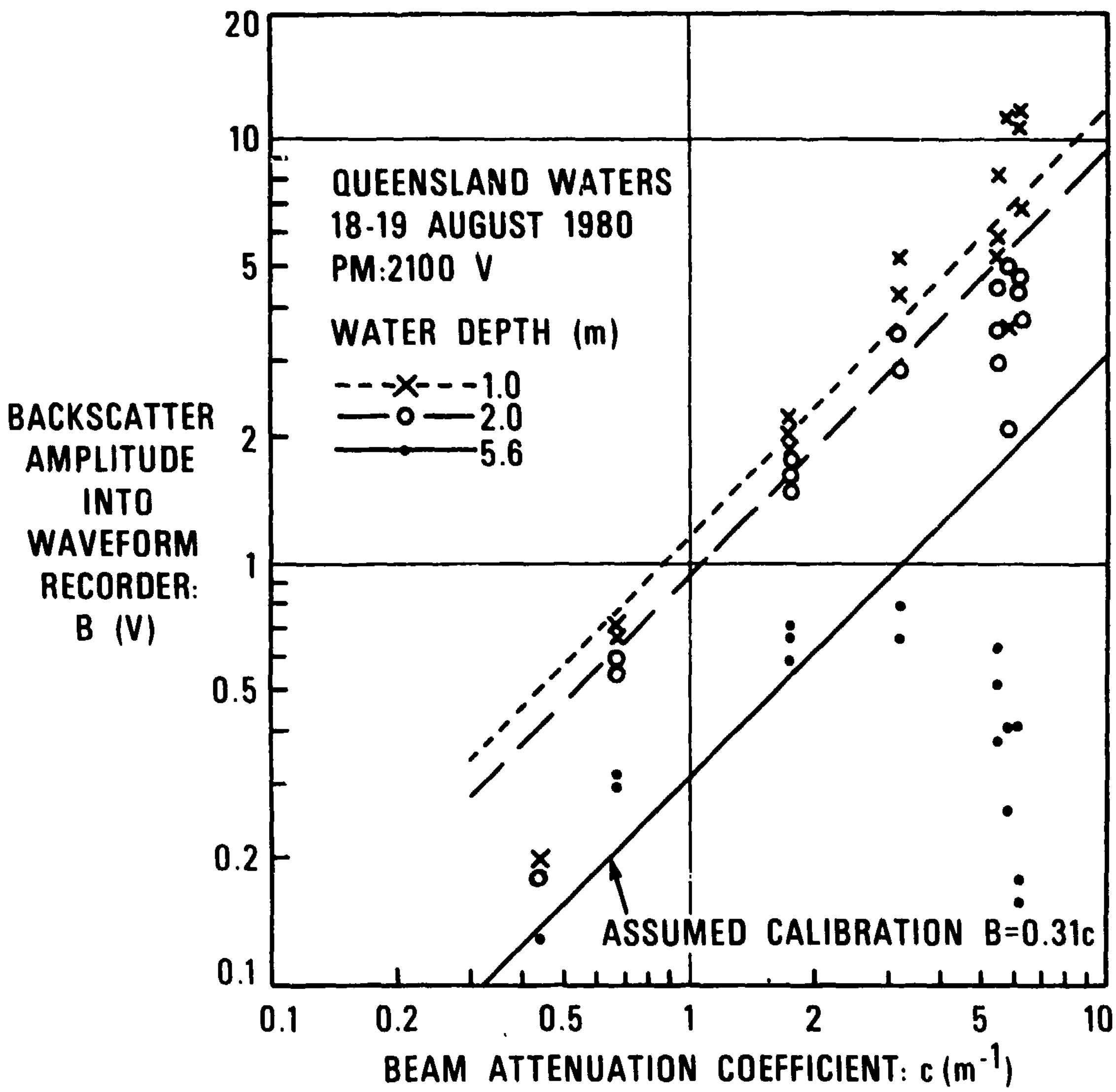

Figure 2. Measured relationship between laser backscatter amplitude and beam attenuation coefficient of sea water

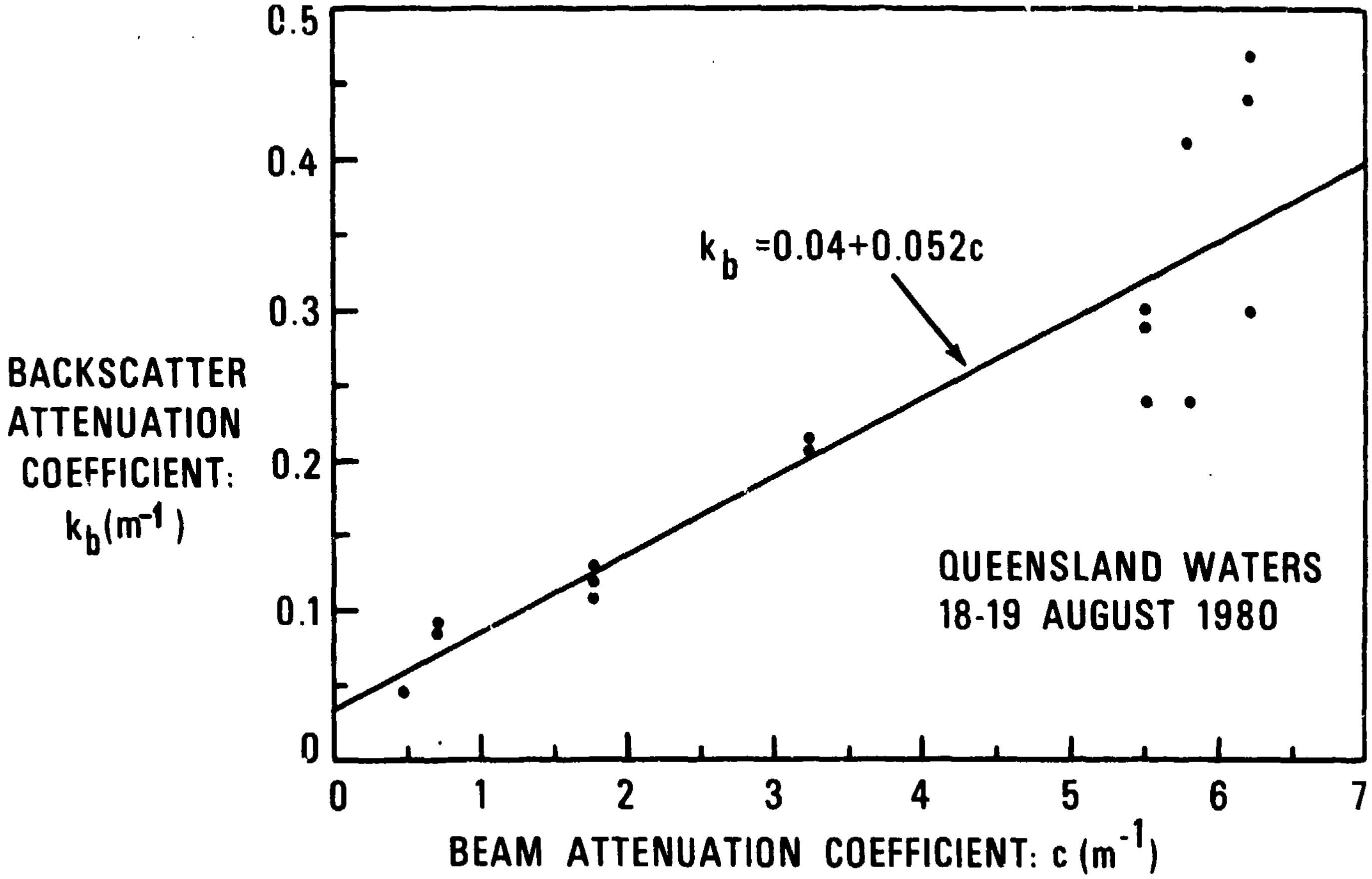

Figure 3. Measured relationship between backscatter and beam attenuation coefficients of sea water

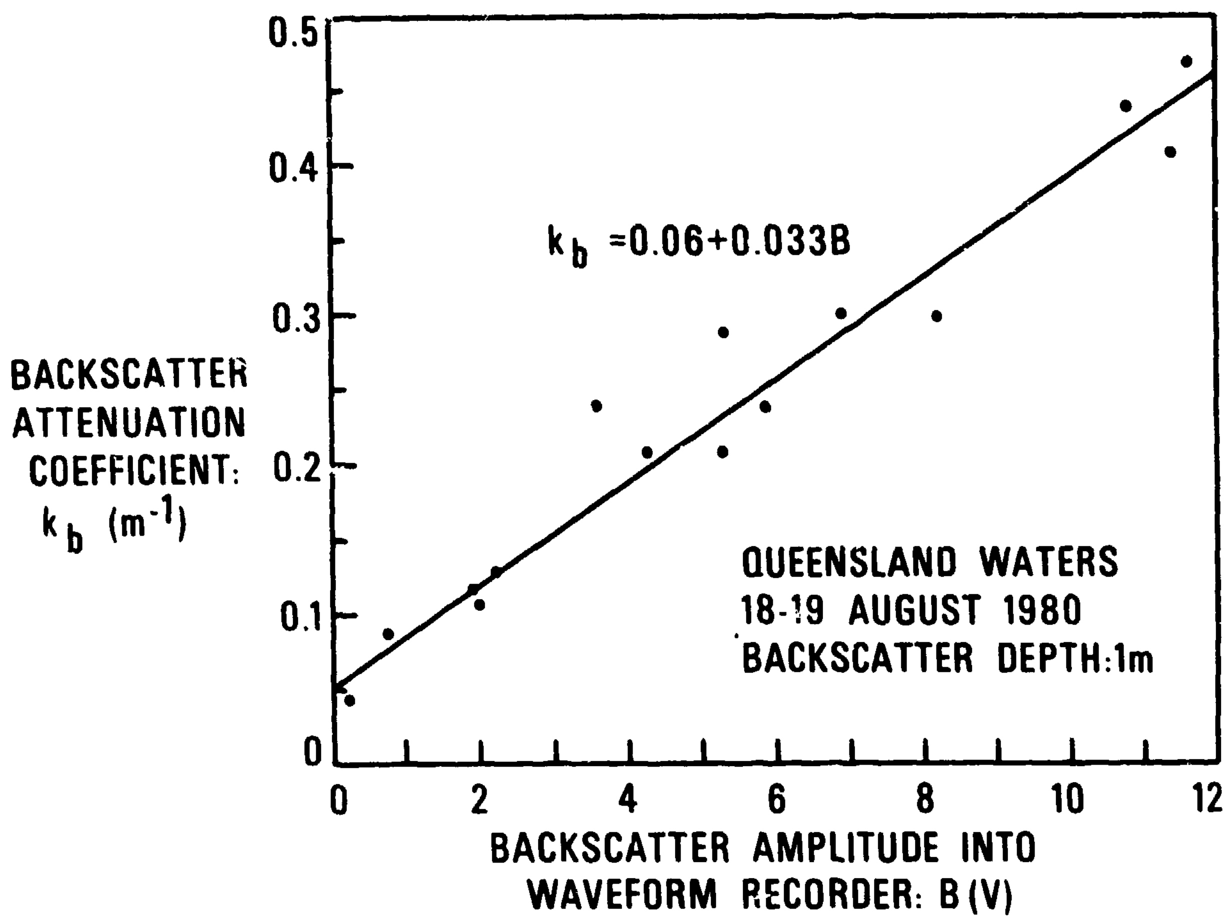

Figure 4. Measured relationship between attenuation coefficient and amplitude of backscatter in sea water

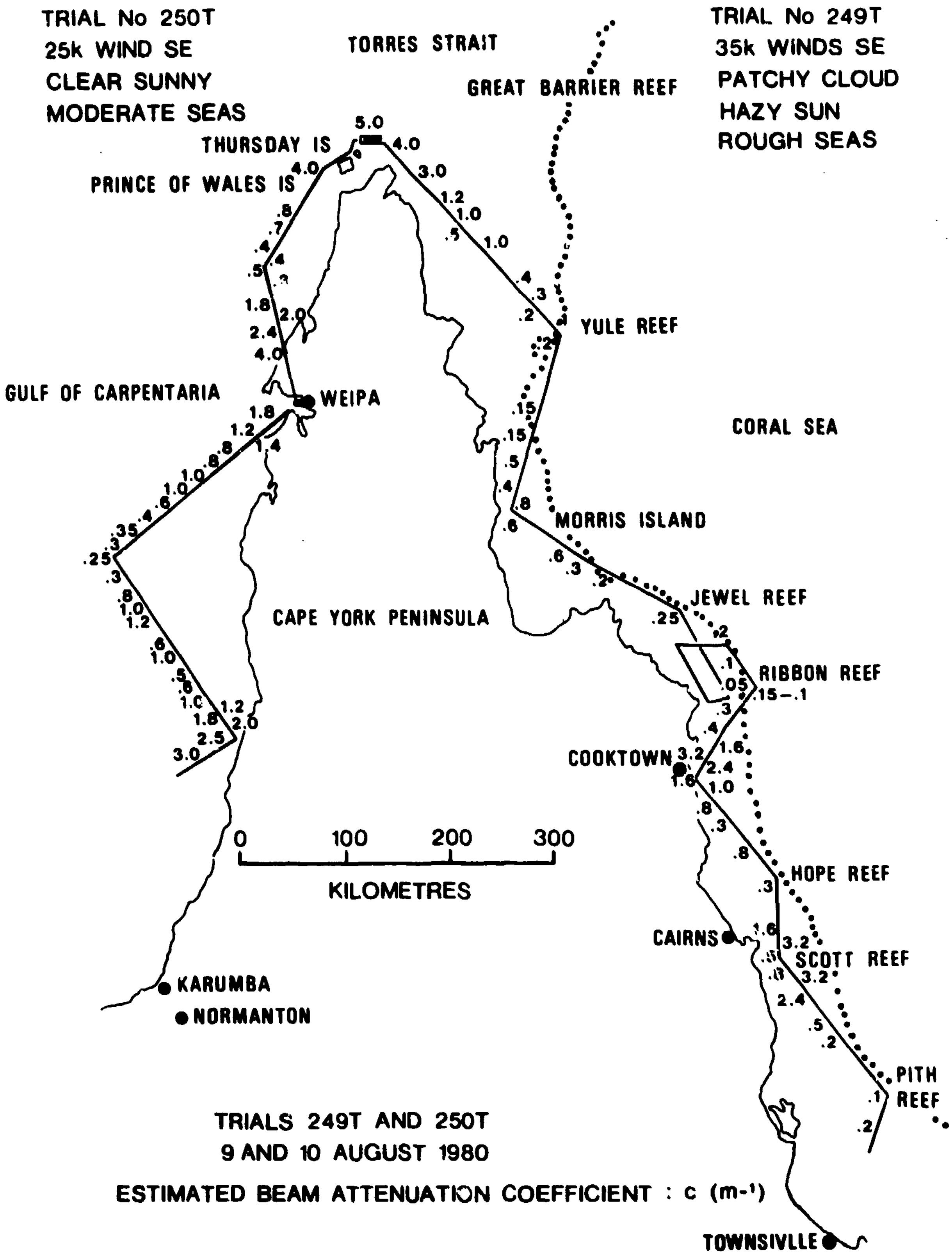

Figure 5. Turbidity of North Queensland waters determined from aircraft measurements of laser backscatter amplitude

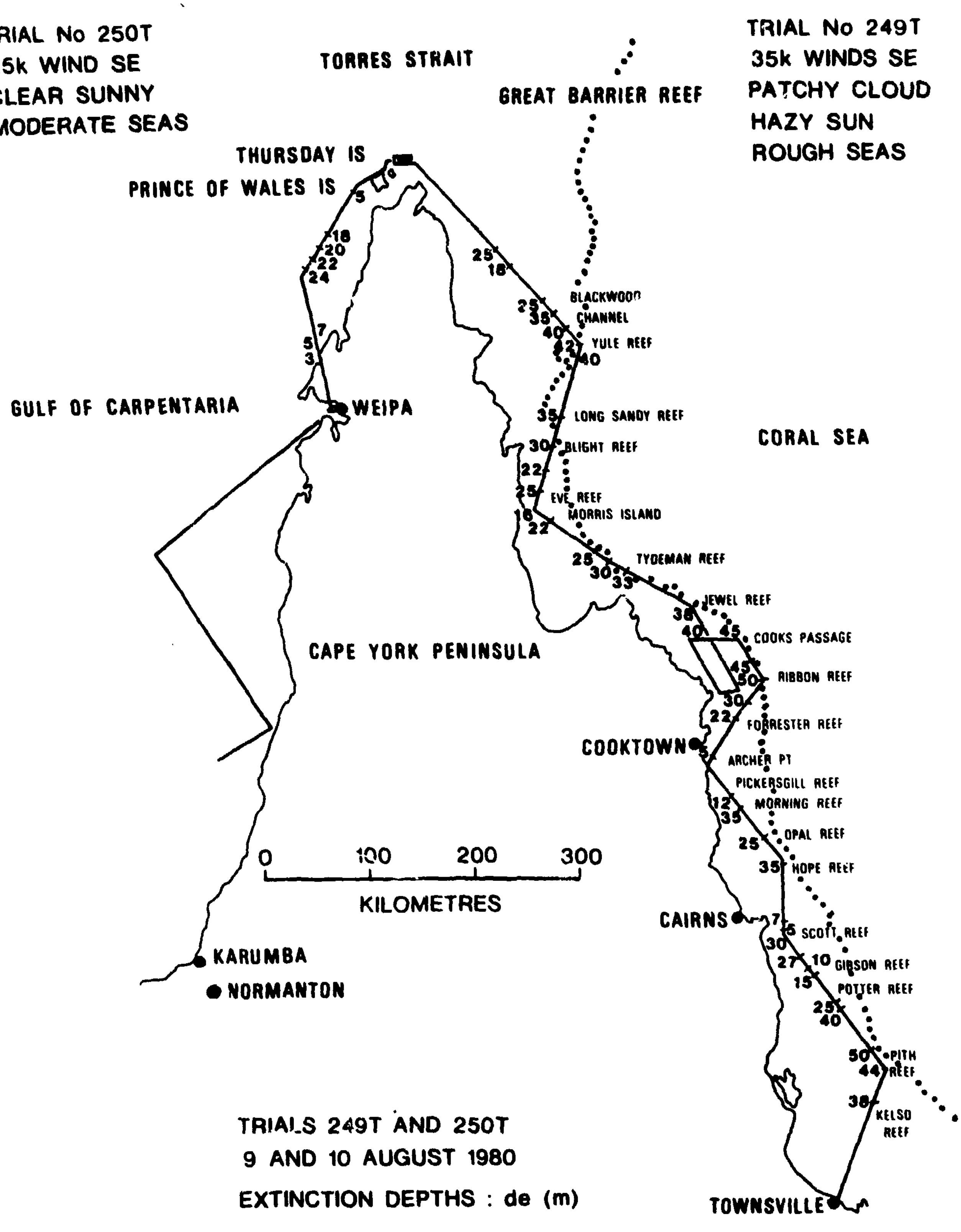

Figure 6. Extinction depths of WRELADS II system in North Queensland waters

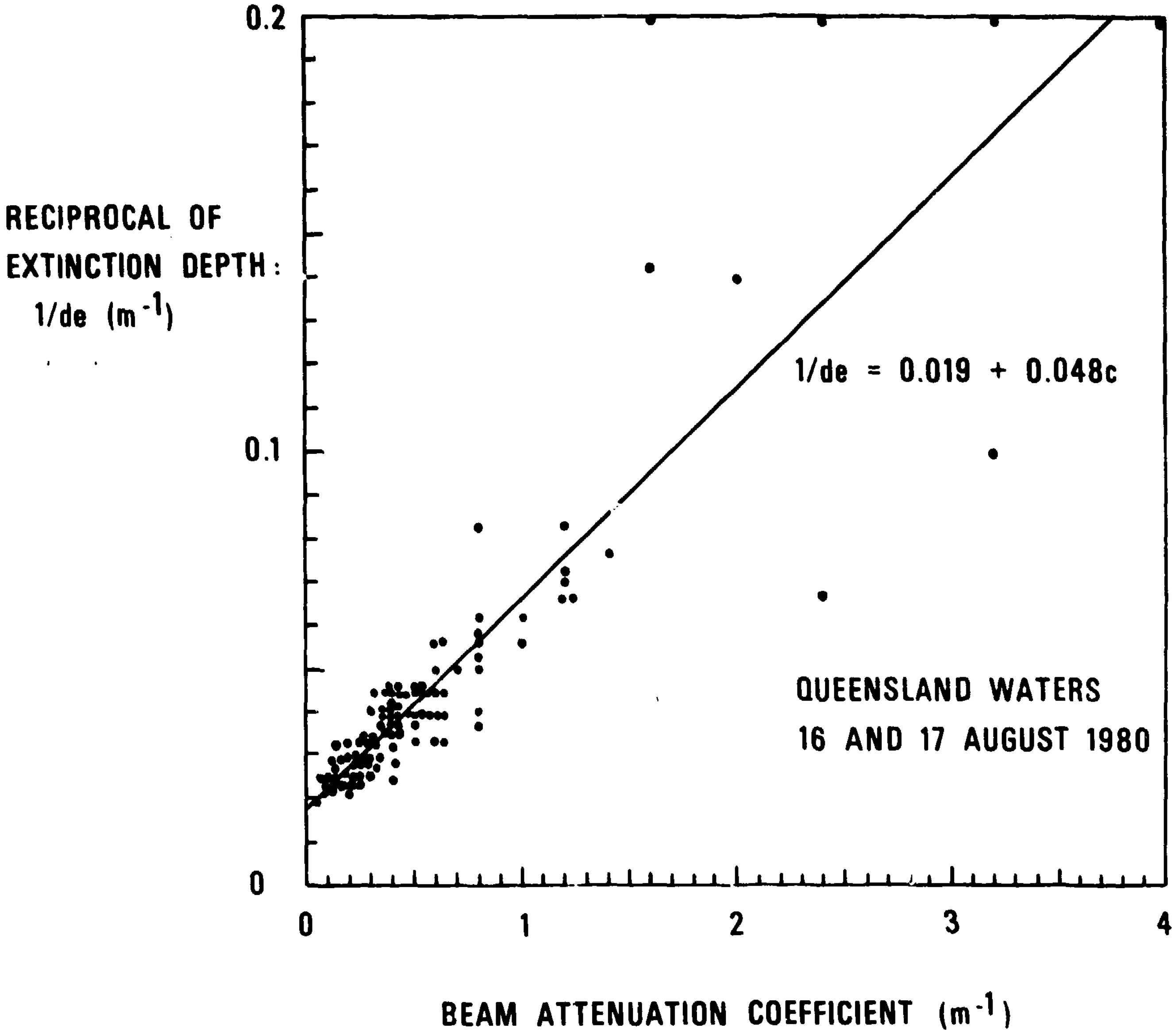

Figure 7. Measured dependence of reciprocal extinction depth on water turbidity

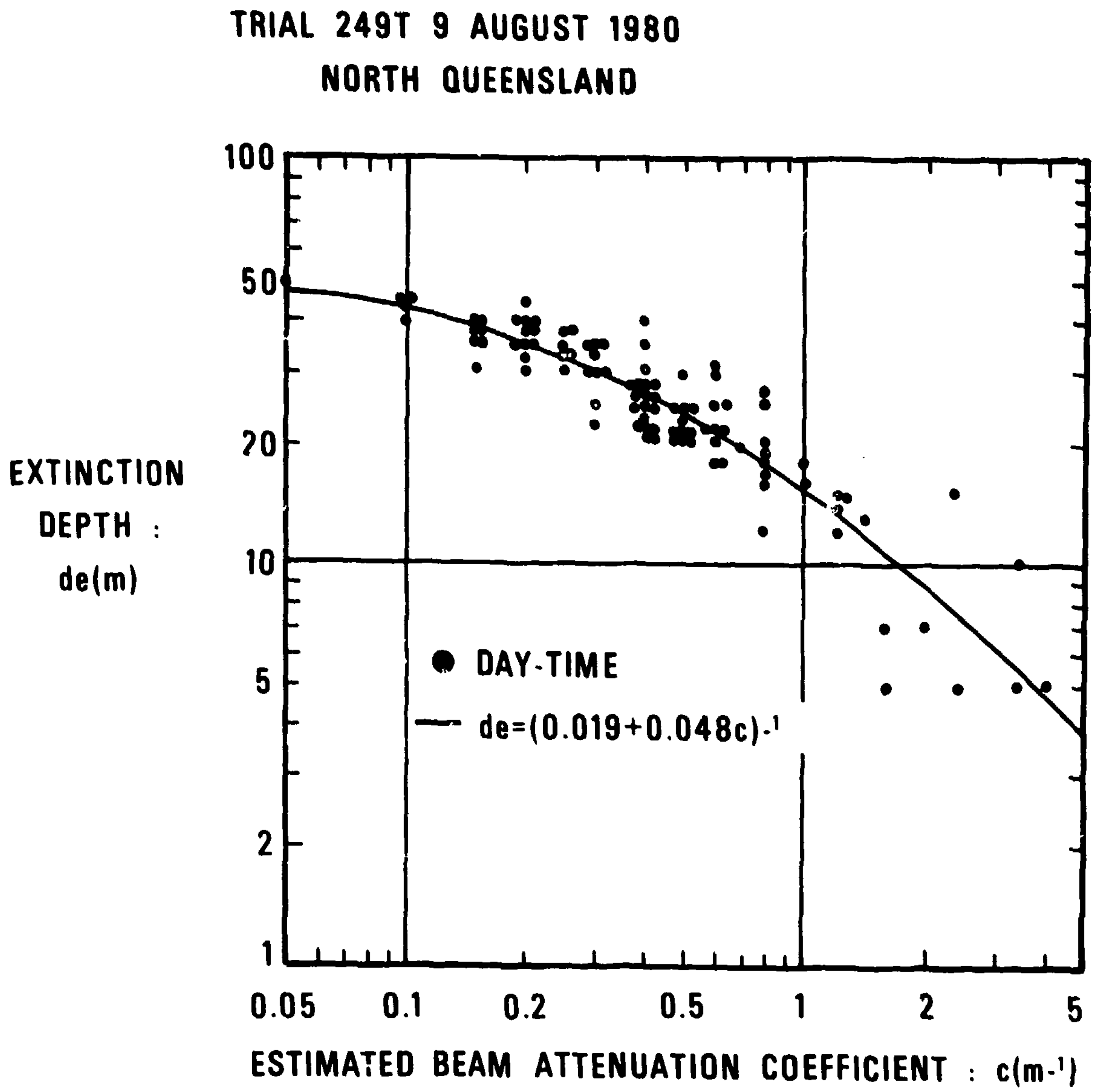

Figure 8. Measured dependence of extinction depth on water turbidity for WRELADS II system

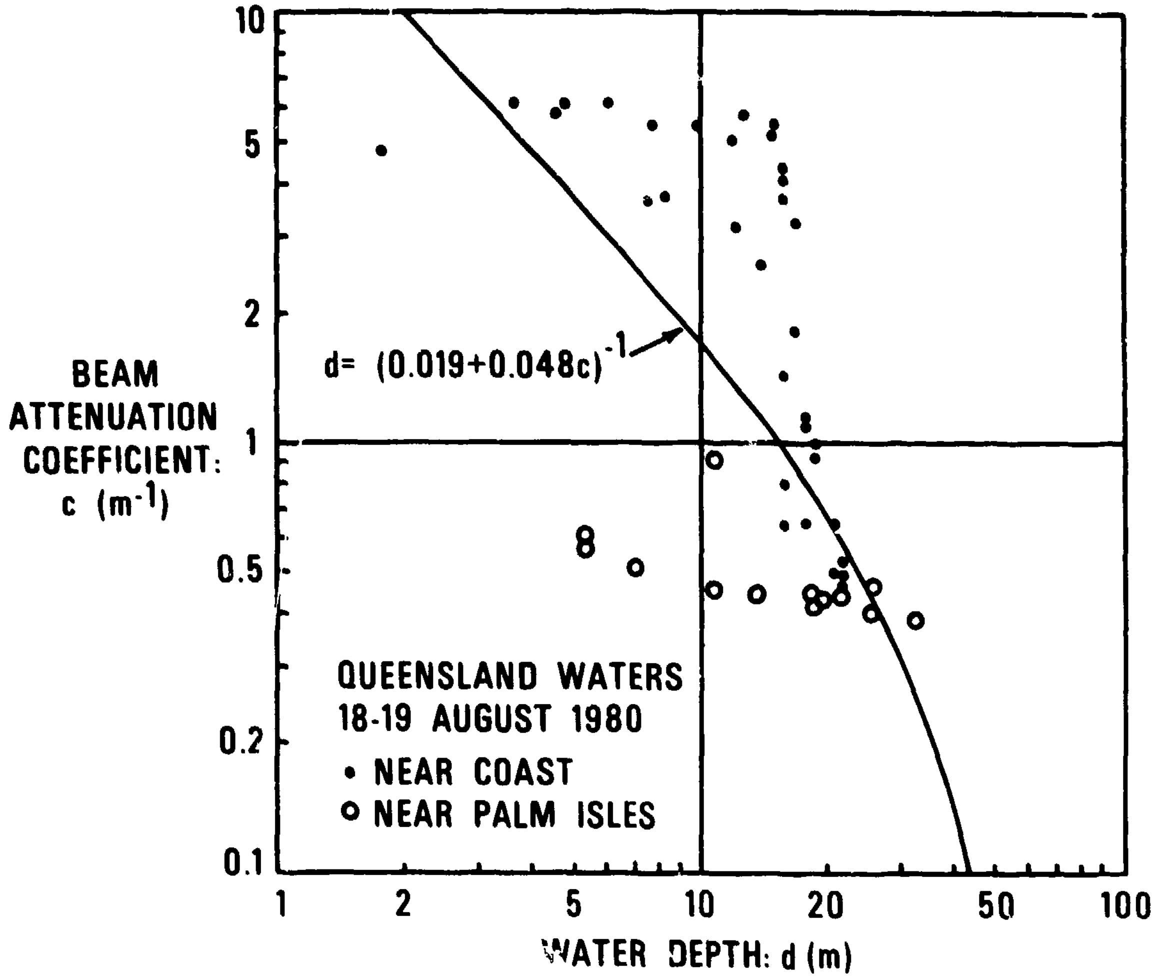

Figure 9. Statistical variation of water turbidity with depth in North Queensland

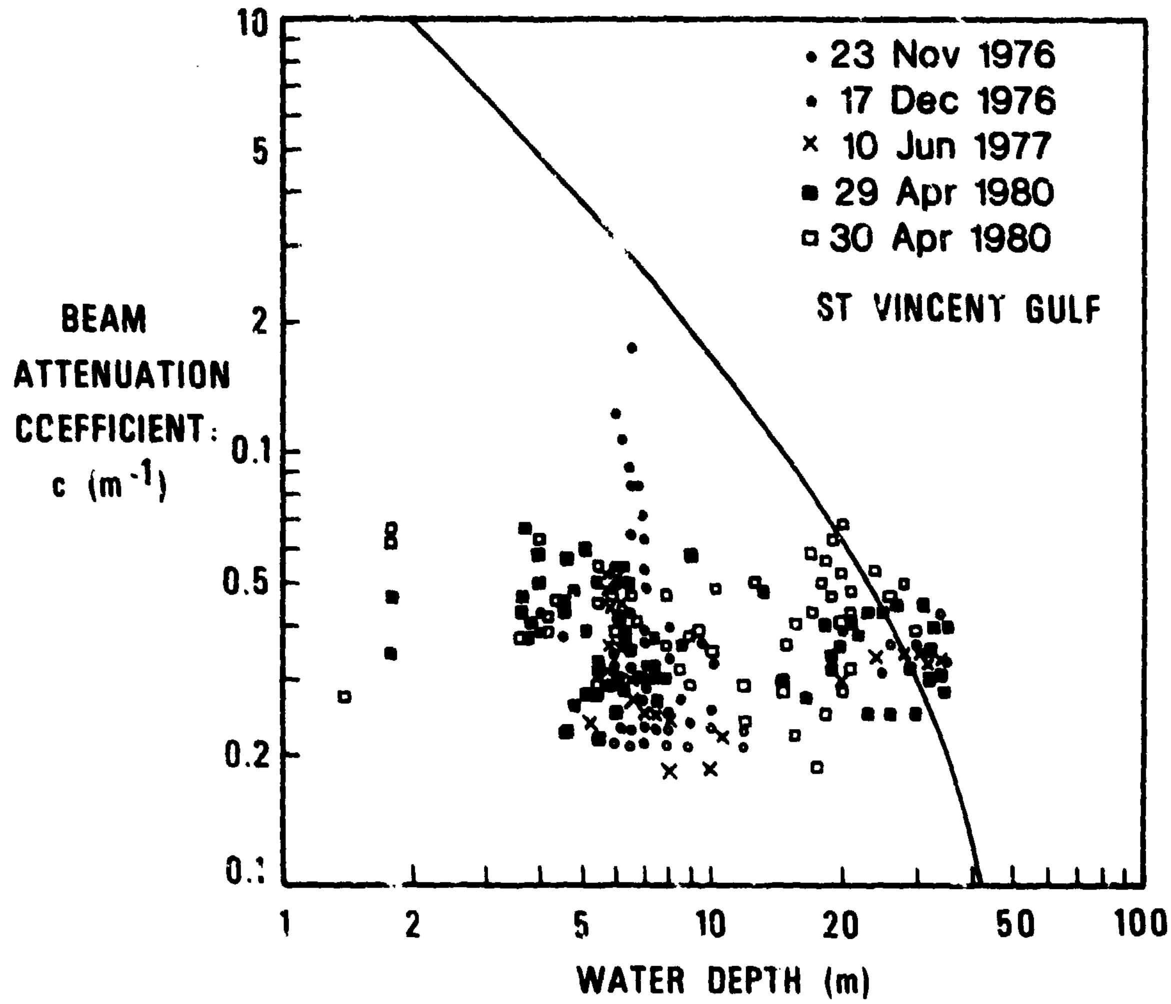

Figure 10. Statistical variation of water turbidity with depth in Gulf St Vincent during calm conditions

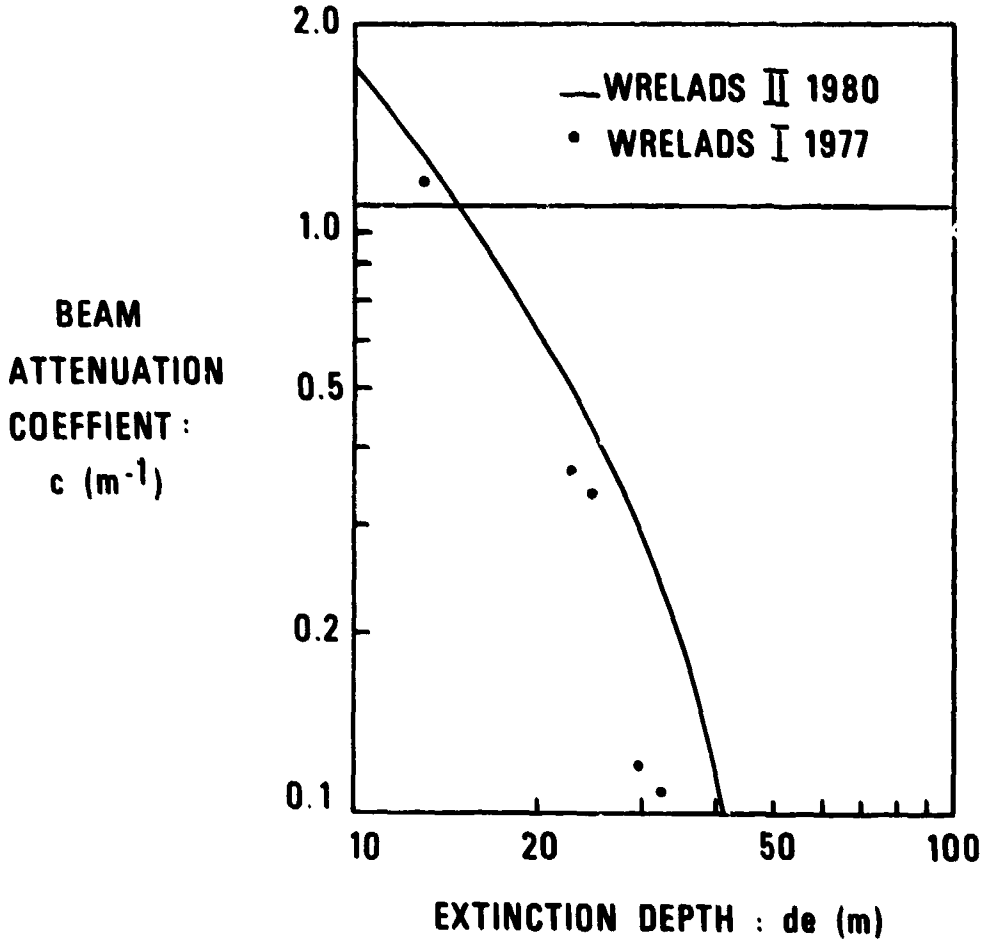

Figure 11. Comparison of depth measuring performance of WRELADS I and WRELADS II systems

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16 SUMMARY OR ABSTRACT:
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(U) The performance of the WRELADS laser airborne depth sounder has been assessed in North Queensland coastal waters from Townsville to Torres Strait. This was achieved by recording water turbidity and maximum sounding depth in the aircraft along the flight path. The parameter used in the aerial survey as a measure of water turbidity was related to beam attenuation coefficient measured from a boat in a separate joint aircraft and boat trial. Data relating the statistical distribution of turbidity to water depth were obtained and compared with the observed performance characteristic in order to indicate the proportion of Queensland coastal waters suitable for sounding with an airborne laser sounder.

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